

Integrated Floodplain Management, Environmental Change, and Geomorphology: Problems and Prospects

Paul F. Hudson and Hans Middelkoop

Abstract Recognition of the failure of old perspectives on river management and the need to enhance environmental sustainability has stimulated a new approach to river management over the past couple of decades. The manner that river restoration and integrated management are implemented, however, requires a case study approach that takes into account the influence of historic human impacts to the system, especially engineering. The process of engineering frequently results in an embanked floodplain to reduce the impact of flooding. It is increasingly recognized that floodplain embankment, while usually effective at minimizing flood risk, results in a variety of adverse consequences to the functioning of the river and associated ecosystem health. New, geomorphic-based approaches, which take into account the different modes of adjustment under the framework of integrated management, are now largely seen as the way to move forward. Implementation of such an approach, however, requires a sophisticated understanding of the fluvial system.

Keywords Integrated floodplain management · Fluvial geomorphology · Embanked floodplains · Lowland rivers · Environmental change

1 Scope and Rationale

The purpose of this volume is to provide a comprehensive perspective on geomorphic approaches to the management of lowland alluvial rivers in North America and Europe. Lowland rivers constitute a distinctive type of fluvial system characterized by broad floodplains, complex flood regimes, and often have laterally active meandering channels. In North America and Europe, many lowland rivers have been heavily managed for flood control and navigation for decades or centuries, resulting

P. F. Hudson (✉)
Leiden University, The Netherlands
e-mail: p.f.hudson@luc.leidenuniv.nl

H. Middelkoop
Department of Physical Geography, University of Utrecht, Utrecht, Netherlands

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in engineered channels and embanked floodplains with substantially altered sediment loads and geomorphic processes. Over the past decade, floodplain management of many lowland rivers has taken on new importance because of concerns about the potential for global environmental change to alter floodplain processes, necessitating revised management strategies that minimize flood risk while enhancing environmental attributes of floodplains influenced by local embankments and upstream dams. Although such floodplains are heavily modified, it remains essential to understand their controlling geomorphic processes to design effective plans for environmental management and restoration (Florsheim and Mount 2003; Singer and Aalto 2009), and to evaluate their longer-term impact on the fluvial system. Concurrently, the science of geomorphology is increasingly recognized as vital for designing effective management for dealing with different forms of global environmental change, thereby placing geomorphologists within a critical team of floodplain management specialists which also includes engineers, planners, and ecologists.

Integrated river management is commonly approached from the drainage basin perspective, which necessitates considering fundamental tenets of fluvial systems, specifically runoff and sediment sources, sediment transport, channel dynamics, and floodplain processes. The following chapters include case studies which emphasize the important role of geomorphology in river-floodplain management. These include case studies which consider the impact of different anthropogenic influences (dikes, dams, cutoffs...) to fluvial processes, as well as management and restoration approaches developed in response to both past and forecasted types of environmental change. European and North American alluvial rivers are of keen interest because of their long documented efforts at floodplain management and river engineering, an abundance of published literature available for syntheses, and because management agencies exist across governmental scales (e.g., local, state, federal). Additionally, because the timescales at which specific management styles have been implemented vary, there are important lessons to be learned by making a comparison across different river systems. Indeed, many ideas about river and floodplain management were exchanged between Europe and North America during the twentieth century (Reuss 2002; Hudson et al. 2008). Flood disasters over the past decade and a general concern about global environmental change suggests a vibrant exchange of ideas between Europe and North America concerning effective floodplain management strategies will continue well into the present century (e.g., US Congress 2005).

The issue of effective river and floodplain management is pressing along large alluvial rivers in North America and Europe, particularly in those regions with a high population density and economic activities (Kundzewicz et al. 2007). Such settings have a complex floodplain geomorphology and sedimentology, possibly influenced by ground subsidence and river avulsion processes (Stouthamer and Berendsen 2001; Aslan et al. 2005; Leigh 2008). These factors influence floodplain adjustment and increase flood risk but were often inadequately considered in the design of "traditional" flood control infrastructure (e.g., NRC 1995; ASCE 2007). Traditional flood control approaches utilized hard engineering to modify floodplain structure. Such approaches often did not consider the inherent dynamics of fluvial

systems which drive abrupt changes over short timescales, the longer-term adjustments to regional controls (such as neotectonics), or the unintended consequences of floodplain engineering which unfold over longer timescales (Hesselink et al. 2003; Hudson et al. 2008; Singer and Aalto 2009). Additionally, these approaches are often focused on “local” management rather than considering the entirety of drainage basin controls. Modern—integrated—floodplain management is inherently more flexible and is designed to minimize flood risk, and at the same time to restore environmental attributes of embanked floodplains by “working with the river” (e.g., Ayres et al. 2014 for European river restoration).

Fluvial geomorphology provides an important conceptual framework and toolkit for design and implementation of river and floodplain management. Although reference to the importance of fluvial geomorphology to floodplain management can be found as far back as half a century, it did not strongly emerge until about the past 20 years within the United Kingdom and continental Europe (Downs et al. 1991; Middelkoop 1997; Middelkoop and Van Haselen 1999; WMO 2004). The inclusion of geomorphic approaches was formally advocated in the European Union’s sweeping “Water Framework Directive” (European Council 2000). Scientific communities in North America have also recognized the importance of floodplain geomorphology to effective management strategies over the past couple of decades, but the importance of integrating geomorphic approaches to floodplain management may be characterized as “patchwork,” occurring basin by basin, with individual states and “river authorities” (management districts) often adapting different approaches for different motivations (Ramin 2004). Indeed, within the USA, there exist strong regional contrasts in expenditures and management styles between the Mississippi basin, the west coast, and the Southern United States (Bernhardt et al. 2005).

Geomorphic approaches to floodplain management include diverse management plans that explicitly consider the physical processes and sedimentological and topographic frameworks in which modern processes function and engineering structures are emplaced (Hudson et al. 2008; Singer and Aalto 2009). Such approaches may include strategies such as dike (levee) realignment to increase the space for flood water retention (WMO 2004), channel planform and migration in relation to bank material (sedimentology), reconnection of meander bends or floodplain bottoms by levee breaches (Florsheim and Mount 2003), water resources and geomorphic processes (Asselman et al. 2003; NRC 2005; ASCE 2007), dike and flood control infrastructure with a knowledge of subsidence rates and neotectonics (Li et al. 2003; Dokka 2006; Törnqvist et al. 2008), and rates of floodplain sedimentation with management of floodplain water bodies (Middelkoop and Van Haselen 1999; Zeug and Winemiller 2009). These approaches require an understanding of the base-line physical processes for successful implementation.

There is much to be learned by examining different river basins across different physical landscapes and governmental settings. In this volume, we compile a range of case studies to consider the varying roles of geomorphology for river and floodplain restoration, and also to consider different approaches overseen by agencies charged with the task of designing effective strategies for floodplain management, and flood control.

2 Channel Dynamics

River management agencies have increasingly becoming aware of the linkages between channel dynamics and geomorphology as related to floodplain management. To date, most large-scale floodplain management plans, particularly for flood control, also include river channel management for bank stabilization and protection of flood control infrastructure. A common approach to flood control is river channelization (straightening) by artificial cutoffs of meander necks and sinuous reaches (Gregory 2006). Channel alignment and stabilization, however, is dependent upon knowledge of the sedimentary framework in which channels are active, specifically the channel-bed material (particle size) and bedload (volume) and the floodplain bank deposits (cohesive or noncohesive) (Frings et al. 2014). Additionally, channelization of sinuous reaches results in channel-bed incision, thereby decreasing the frequency of overbank events and sedimentation.

An important consideration is that channel bank protection infrastructure (groynes, revetments, etc.) was commonly designed for specific discharge regimes based on historic time-series data. Considerable modeling efforts have simulated changes in discharge regime (e.g., timing and magnitude of floods) in relation to regional climate change scenarios (e.g., IPCC 2007), but it is also essential to consider changes in rates of channel bank erosion and planform geometry as rivers adjust to changing discharge regimes. Most flood-control infrastructure was constructed without considering river channel avulsion processes. While perhaps requiring a century or so to occur, the initiation of a channel avulsion influences modern fluvial processes over decades, about the same timescale in which flood-control infrastructure is conceived and implemented. The slow, gradual process of channel switching changes discharge allocation and results in channel-bed aggradation that subsequently alters stage-discharge relations and flood regimes, which often requires further channel engineering as well as modification to flood-control infrastructure.

3 Embanked Floodplain Geomorphology, Flood Control, and Environmental Management

Flooding is one of the most significant ways in which climate change is manifest (AR5/IPCC 2014). Floods are natural events vital to river and floodplain geomorphic and ecosystem processes (NRC 2005). When humans are impacted, however, floods become “natural disasters” (White 1945; WMO 2004; Pinter 2005; Benito and Hudson 2010). Knowledge of fluvial processes and sedimentology is an important consideration in the design of flood control. For example, painful lessons were learned after the 2005 Hurricane Katrina disaster as regards the design and placement of dikes and flood walls in relation to subsurface sedimentology and changing topography. This is a critical issue to floodplain management and flood control, because as subsidence rates and climate change scenarios become integrated into

flood forecasts it requires reengineering, which includes fortification and heightening or relocation of dike sections. An additional consideration concerns the linkages between sedimentology (historic floodplain geomorphology) and alluvial groundwater. This is vital as concerns the floodplain storage capacity for flood waters, but also because of controls on subsurface flow and dike seepage, which initiate sand boils (Davidson et al. 2013), as well as the management of groundwater resources.

Knowledge of embanked floodplain geomorphology is also vital to effective environmental management. A well-documented approach involves the removal of cohesive overbank sediments (clay—fine silt) for the creation of side channels and wetlands for environmental management and restoration. In densely populated regions, such as northern Europe, this becomes an essential approach because of limited space for dike relocation and the recognition of the need to adapt flood-control plans for climate change. Nevertheless, the removal of fine-grained top stratum deposits creates a risk of enhancing dike underseepage (Cobb et al. 1984) and should only be attempted with detailed knowledge of the underlying floodplain sedimentary architecture.

Large lowland river floodplains are mosaics of sedimentary deposits and topographic features created by various different geomorphic processes, which influences alluvial aquifers and surface flow paths of water, sediment, and nutrients (Nienhuis and Leuven 2001; Thoms 2003). Within embanked floodplains such processes represent fundamental controls on the dynamics and maintenance of ecosystems associated with floodplain water bodies such as oxbow lakes (Zeug and Winemiller 2009), but also artificially constructed water bodies such as dike breach ponds and borrow pits associated with the construction of flood-control dikes (Cobb et al. 1984; Jurada et al. 2004). Our understanding of overbank processes has advanced tremendously over the past couple of decades, particularly flood-pulse dynamics (Tockner et al. 2000), sedimentation (Day et al. 2008), channel-floodplain connectivity, as well as the exchange of nutrients and ecological processes. Integrating knowledge of these processes with floodplain management lead to more effective ecological management (NRC 2005). For example, the intentional breaching of levees to distribute sediment and nutrients has been found to be very effective at replenishing floodplain wetlands (Florsheim and Mount 2003), and is becoming a common option for integrated floodplain management.

This volume presents distinct approaches utilized for floodplain management of large alluvial rivers in Europe and North America, with particular focus to the role of geomorphology. The river basins examined in the subsequent 12 chapters (Fig. 1) provide a representative coverage of the drainage of North America and Europe, taking into account a range of climatic and physiographic provinces. The case studies are large basins and collectively drain a wide swath of North American and European landscapes, and as such can be viewed as representative of many other situations. The river basins include the (1) Sacramento (California, US), (2) San Joaquin (California), (3) Missouri (Missouri), (4) Red (Manitoba and Minnesota), (5) Mississippi (Louisiana), (6) Kissimmee (Florida), (7) Ebro (Spain), (8) Rhone (France), (9) Rhine (The Netherlands), (10) Danube (Romania), and (11) Volga (Russian Federation) Rivers. The case studies covered in this chapter span



Fig. 1 Featured drainage basins of North America and Europe

a range of fluvial modes of adjustment, including sediment, channel, hydrologic regime, floodplains, as well as ecosystem and environmental associations.

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